Space Exploration SAR: A Digital Beamforming Synthetic Aperture Radar for Planetary Science. Lynn M. Carter[1], Rafael F. Rincon[2] , Daniel Lu[2], David M. Hollibaugh Baker[2], Cornelis F. du Toit[2], Catherine D. Neish[3,4], Martin Perrine[2], [1]University of Arizona, Lunar and Planetary Laboratory (lmcarter@email.arizona.edu), [2]NASA Goddard Space Flight Center, [3]University of Western Ontario, Dept. of Earth Sciences, [4]The Planetary Science Institute.

Introduction: The near-surface of Solar System objects – the upper tens of meters – contain key information about their geologic evolution. These upper layers can contain ice deposits, layers from prior episodes of volcanism, buried fluvial channels, former lake deposits, buried boulders from impacts, caves, or resources. This near-surface region is close enough to the surface to be accessible to future human or robotic explorers and contains information important to understanding surface evolution.

We are developing a next-generation orbital digital beamforming synthetic aperture radar, called Space Exploration SAR (SESAR), that will provide science data at depths and resolutions that are well-matched to near-surface science objectives (Fig. 1). SESAR will operate at P-band (70 cm) wavelengths and use high bandwidths (100 MHz) to achieve meter to tens of meter scale spatial resolutions with full polarimetry.

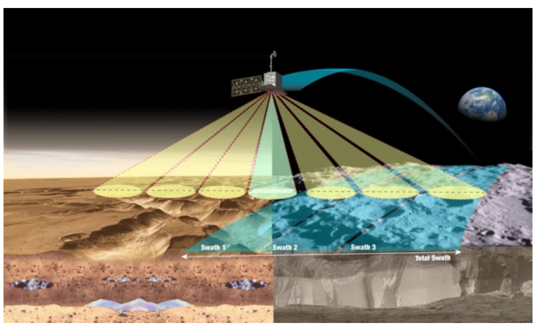

Fig. 1: SESAR is a P-band (425 MHz) digital beamforming radar that would penetrate meters into the surface of Mars (left) and the Moon (right) to reveal buried features.

Science Objectives: SESAR will be a significant improvement over prior planetary orbital SARs such as the Magellan radar and Mini-RF radar on Lunar Reconnaissance Orbiter (LRO) because it will have higher resolution (meter-scale), penetrate deeper into the surface (several meters), acquire full polarimetry for the first time, and employ programmable digital beamforming technology for flexible data collection. It would be particularly useful for the Moon and Mars, where a regolith-penetrating radar could reveal buried features. However, SESAR is modular and can be easily adapted for missions to other planets, moons and small bodies.

At the Moon, SESAR could image through the regolith to characterize the near-surface stratigraphy of the Moon in unprecedented detail not available to any other instrument. It would complement the much longer wavelength data of the Kaguya Lunar Radar Sounder [1], be a good comparison for the Yutu rover ground penetrating radar data [2], and present a very different view of the surface than the shorter wavelength Mini-RF radar [3]. Prior imaging with the Arecibo Observatory P-band radar system demonstrates the incredible science that is available at this wavelength (Fig. 2) [4]. Higher-resolution (few meters) morphologic mapping and polarimetry with SESAR would reveal details about the volcanic processes that built the mare (e.g. size of flows, emplacement scenarios) and would enable comparisons to terrestrial analogs. SESAR will be able to image buried lava channels [4] and detect near-surface lava tubes. SESAR can also be used to search for buried ice deposits at greater depths than the Mini-RF radar, and in craters that could not be observed from Earth using the Arecibo radar system [5].

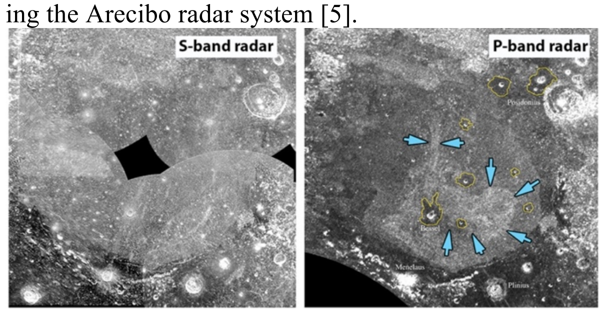

Fig. 2: S-band (12.6 cm wavelength) data show primarily bright crater ejecta at or near the surface. In contrast, P-band (70 cm wavelength) radar data reveal buried lava flows beneath the surface of Mare Serenitatis [4]. These images were acquired using the Arecibo Observatory radar at 80 m/pixel and 200 m/pixel, respectively. SESAR can obtain 30 times better resolution than is achievable from Earth at P-band.

Locating habitable regions, finding water, and determining the evolution of Martian hydrology and cryosphere is a primary goal of Mars exploration [6]. Current sounding radars in orbit at Mars (SHARAD and MARSIS) have wavelengths that are too long to detect the upper interface between ice and the surface lag deposits. SESAR can penetrate through meters of mid-latitude mantle deposits in search of near-surface ice deposits, including regions where ice is exposed in cliffs [7], to determine the near-surface cryospheric water budget. The instrument's nadir beam pointing would be used in sounding mode to produce profiles of time delay vs. along track distance similar to ground penetrating radars like SHARAD, but at shallower depths. SESAR would also be able to determine the structure and stratigraphy of buried fluvial channels and ancient lakes, and would map and characterize buried volcanic units and lava tubes.

Digital Beamforming: Unlike a traditional single-beam approach, a digital beamforming radar has the ability to implement SAR imaging polarimetry, high-resolution altimetry (Delay/Doppler altimeter), nadir sounding, and multi-beam scatterometry with the same radar platform and without slewing the antenna [8]. Look-angle can also be selected with no slewing to produce stereo or to acquire polarimetry over multiple incidence angles. The ability to generate polarimetric scattering versus incidence angle profiles for modeling will be a completely new capability, and not something that can realistically be achieved with conventional radar systems due to the need to roll the spacecraft to significantly change incidence angles. This will also facilitate the collection of interferometric and stereo topography data if needed for the science requirements.

In SAR imaging mode, SESAR will image the surface or subsurface at meter-scale resolution over one or multiple beams. Each of the beams will measure up to four polarizations to facilitate retrieval of the Stokes parameters, from which a broad suite of scattering mechanisms associated with particular geological processes can be assessed. A high-gain single beam on either side of the flight track will be able to image areas that require increased subsurface penetration or higher signal-to-noise ratio.

The multi-mode operation of SESAR allows for “smart” data collection, where one radar system can provide different data types depending on the science requirements defined for each surface target. This is a new way to use a planetary radar, and the flexibility will provide the capability to meet large numbers of science goals with one mission.

SESAR Design and Development: The SESAR radar is based off the successful EcoSAR and DBSAR airplane radar systems designed at NASA GSFC [9, 10]. It employs a modular design where the digital electronics are distributed into panels with active subarrays (Fig. 3). This allows the radar instrument to be modified, adding or removing panels and corresponding electronics, to accommodate different mission requirements.

A key goal of the SESAR development was to reduce the power and mass of the system. To reduce the power, a Frequency Domain Multiplexing (FDM) system was developed for the digital electronics that will reduce the required power by at least a factor of 4 while preserving the full beamforming capability and full-polarimetry operation [11]. We have also developed a light-weight and modular antenna design that permits folding the antenna panels around the spacecraft for launch, and we have built and tested a prototype antenna subarray in the GSFC anechoic chamber [12]. The Radar Digital Unit (RDU) for SESAR has been concurrently developed under the NASA SBIR program.

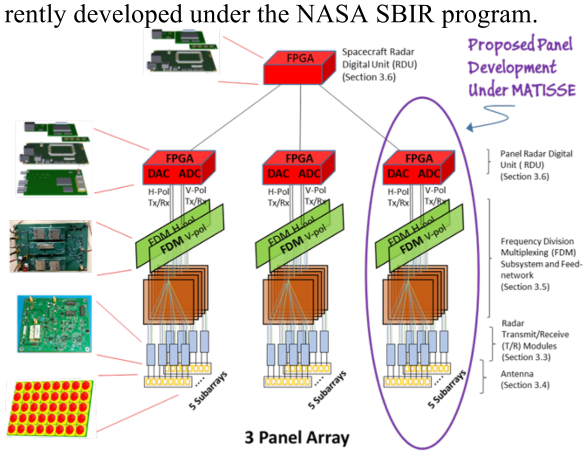

Fig. 3: SESAR's modular approach consists of instrument panels composed of four subsystems. This enables scaling of the instrument to match the orbit and science goals required for different planetary targets.

Future Plans: SESAR was recently awarded a MATISSE proposal that will lead to a TRL 6 instrument. We will assemble, test, demonstrate, and characterize a fully populated radar panel with all four subsystems (Fig. 3). SESAR’s innovative approaches to developing a low mass, low power SAR at P-band will enable exploration of the near-surface environment, a previously mostly unexplored region that holds the answers to many science and exploration systems questions.

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